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Calibration and Testing of a Large-Area Fast-Neutron Directional Detector

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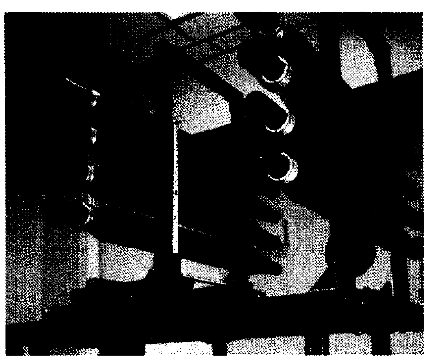
Abstract **– We have developed a new directional fast-neutron detector based on double proton recoil in two separated planes of plastic scintillators with position-sensitive readout. This method allows the energy spectrum of the neutrons to be measured by a combination of peak amplitude in the first plane and time of flight to the second plane. The planes are made up of 1-m long, 10-cm high paddles with photomultipliers at both ends, so that the location of an event along the paddle can be estimated from the time delay between the optical pulses detected at the two ends. The direction of the scattered neutron can be estimated from the locations of two time-correlated events in the two planes, and the energy lost in the first scattering event can be estimated from the pulse amplitude in the first plane. The direction of the incident neutron can then be determined to lie on a cone whose angle is determined by the kinematic equations. The superposition of many such cones generates an image that indicates the presence of a localized source. Setting upper and lower limits on the time of flight allows discrimination between gamma rays, muons and neutrons. Monte Carlo simulations were performed to determine the expected angular resolution and efficiency. These models show that the lower energy limit for useful directional events is about 100 keV, because lower energy neutrons are likely to scatter more than once in the first plane. Placing a shadow bar in front of the detector provides an alternative way to obtain the direction to a point source, which may require fewer events. This method also can provide dual capability as a directional gamma detector.**

SUMMARY

We have previously reported on the construction of an 8-element double-scatter neutron detector and demonstrated the principles of directional fast-neutron detection and neutron-gamma discrimination by time of flight [1,2]. In that prototype, the possible locations of scattering events were defined by 12.5-cm disk-shaped plastic scintillators, each attached to its own photomultiplier. There were only 4 pixels in each plane, giving a limited set of possible scattering angles, and large uncertainties in those angles. Also, the absolute efficiency was reduced by the dead spaces between the disks. Therefore, although that design could locate a point source at distances up to about 9 meters, it was unsatisfactory because it produced streaky images with non-uniform response and required long acquisition times. Analogous results have been obtained by Mascarenhas and coworkers using an 8-element design.

In this paper, we report on the performance of a larger area (40 cm x 100 cm) double-scatter neutron detector with continuous readout of the position of an event in the horizontal direction (Fig. 1). With four front and four back paddles stacked vertically, there are many possible scattering angles, and the area is fully tiled for high efficiency. There are some similarities to the MONA detector, which was designed for much more energetic neutrons than are produced by fission sources [3]. Our system is modular and can be easily expanded to 80 cm high by adding more paddles.



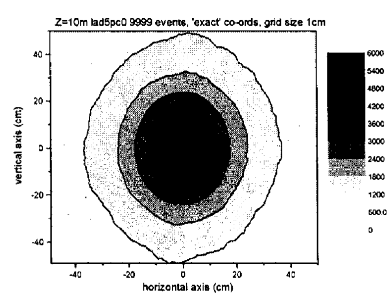


Fig. 1. Configuration of plastic scintillator paddles in the large-area double-scatter directional neutron spectrometer, and simulated image of a point source at a range of 10 m by MCNPx modeling.

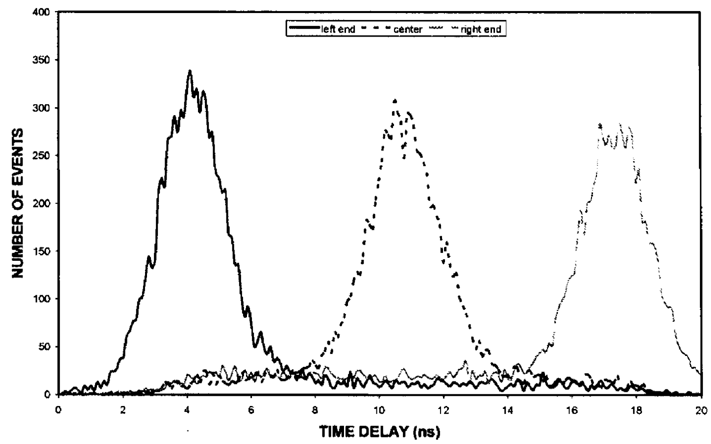


Fig. 2. Distribution of time delays between pulses detected at the ends of a scintillator paddle, for three different gamma source positions. With the existing 1 GHz digital electronics, the timing resolution is about 2.4 ns fwhm, but it may be possible to improve this performance with higher bandwidth timing electronics.

The position sensing of the paddles using the time of arrival of the light pulses propagating in the plastic has been calibrated empirically using gamma sources moved along the surface of the scintillators in steps of 10 cm. Examples of the time distributions obtained from a ^{60}Co source are shown in Fig. 2. We estimate the full-width at half-maximum (fwhm) of these distributions to be 2.4 ns but their centroids can be determined much more precisely. Calibration curves of time difference versus source position were obtained empirically for both front (thin) and back (thick) paddles using both Co-60 and Cs-137 sources. In the plots shown in Fig. 3, the slopes of the fitted lines correspond to a velocity of light in the plastic of 7.6 cm ns^{-1}.

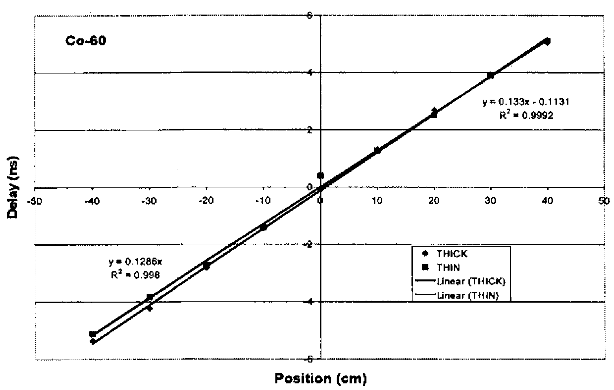


Fig. 3. Calibration plots of time delay as a function of source position.

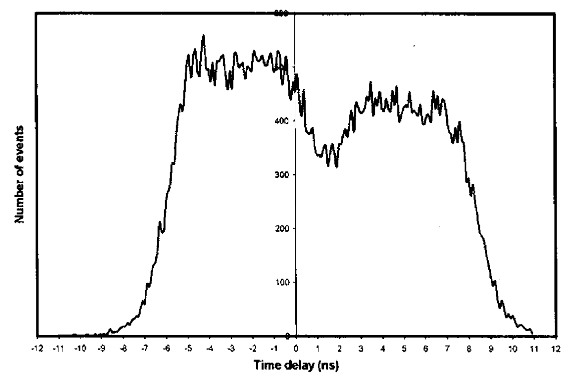


Fig. 4. Response of paddle with 10-cm wide shadow bar.

The large area instrument, once fully integrated, is expected to provide better images of a distant point source than the 8-disk array in a much shorter time, without the artifacts introduced by the small number of pixels. In addition, the continuous nature of the position sensing in the front layer allows an independent method of finding a localized source, using a shadow bar in front of the paddles. This method has the potential of indicating a pointing direction (see Fig. 4) for both a gamma source and a neutron source, probably requiring fewer events and shorter acquisition times than the method of overlapping cones.

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